Draft AT Doc. No. AT/20.1.1/017

A Brief Look at AT Calibration

D.L. Jauncey

Flux Density Calibration

The AT requires for flux density calibration a number of unresolved sources, strong at all frequencies and with accurately known, stable flux densities, widely distributed over the southern sky.

This requirement carries within it internal conflicts, the degree of conflict depending on the angular resolution. The basic conflict is as follows:

(a) Non variable sources usually have optically thin radio spectra of the form $S \alpha \nu^{-\alpha}$ (where $\alpha \sim 0.7$) and are frequently extended on an arc second scale.

(b) On the other hand the compact sources that are strong at all frequencies ($\alpha \sim 0$) are usually variable, both in intensity and structure (on a milli-arcsecond scale). Moreover, half of these compact flat spectrum sources contain nearby associated diffuse structure which makes them unsuitable for flux density calibrators.

For the compact array there may be a small number of sources that meet the flux density calibration requirements, though it should be stressed that the number is likely to be no more than 2 or 3. For example, in the region $0° > \delta > -45°$, where the strong sources have been surveyed with the VLA at 6 and 20cm wavelengths (Perley 1982), only one source, 0237-233 meets the requirements of being strong (> 3Jy), unresolved, with no detectable nearby structure ($\leqslant$ 0.4% of the core) and that is known to be non variable (Klein and Stelzried 1976).

South of the zenith little information exists on source structure on the angular scale to be sampled by the AT.

It is therefore suggested that a programme be implemented as soon as possible to attempt to determine likely flux density calibrators south of

-45° declination, and to determine their radio structures and monitor their flux densities over a wide range of frequencies, in preparation for the AT.

A possible scenario for the AT would then be to use the small number of prime flux density calibrators to monitor the fluxes of a larger number of unresolved, but probably variable, secondary calibrators.

For the long baseline array, its milliarc-second resolution means that even sources like 0237-233 are unlikely to be LBA flux density calibrators. The SHEVE experiment found, for example, that 0237-233 is a 42 mas double, and therefore unsuitable as an LBA flux density calibrator.

VLBI observations on baselines of length several thousand km show that few, if any sources remain totally unresolved at this resolution. Moreover, any sources that are unresolved on the LBA are even more likely to be flux density variables.

It is unlikely that any sources will be found that meet the primary requirement outlined in the opening paragraph. Consequently a different approach will be needed for the LBA flux density calibration. One such scheme is outlined below.

The first step is to determine the relative antenna gains. For example this can be done provided unresolved components can be found. Suppose that three baselines AB, BC, CA all show visibility curves that are constant, implying a single component unresolved on these three baselines, then

$$\frac{G(A)}{G(B)} = \frac{S(AC)}{S(BC)}$$

where G(A) is the gain of antenna A, and S(AB) is the observed cross correlation on baseline AB.

This procedure still, however, leaves the gain of one antenna to be used as a reference.

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A one-sided approach is then to find those sources which are

(a) unresolved on the compact array and,
(b) unresolved, at least on the shorter LBA baselines.

That source which is least resolved is then that source with the smallest ratio of compact array flux density to correlator output on the shorter LBA baselines. Consensus amongst several sources would then establish some reliability to the final LBA flux density scale.

Such a procedure is not guaranteed of success, since neither those sources with unresolved components nor those that are unresolved on the shorter baselines are yet known. A significant start could, however, be made with the Parkes-Tidbinbilla Interferometer at 2.3 and 8.4 GHz, in determining those sources with low ratios of total flux to correlated flux on this baseline.

Phase Calibration; the Compact Array

The AT requires for phase calibration a relatively dense celestial distribution of unresolved sources, strong at all frequencies and with accurately known and stable positions.

This requirement should be readily met for the compact array from amongst the strong variable sources. As with the flux density calibration, however, the requirements for the LBA are likely to be less easily met as the variable sources often exhibit rapid structural variability, at least at milli-arcsecond scales.

It is important to remember that all of those beautiful "self-cal" procedures that grew out of "phase-closure" (Rogers et al. 1974, Jennison 1958) improve the quality of the map, but provide no information on the position of the map.

Phase calibration has two main astrophysical goals,

(a) to provide map registration so that maps at different frequencies can be reliably overlaid, and
(b) for phase referencing, so that the effects of the atmosphere and ionosphere can be largely removed before making maps.

These are discussed separately below.

Map Registration

Perhaps the most demanding registration requirement will come with the launch of the Hubble Space Telescope, (hopefully) several years before AT completion. HST has a beam width of typically 0.1 arcsecond, pointing capability of 0''007 and an astrometric capability of 0''002. At the very least, one would like to be able to register HST and AT maps to something like one tenth of the HST beamwidth, i.e. ~ 0''01.

For the compact array at 10 GHz, λ/D = 1''0 for the full 6 km baseline, so that a 0''01 positional uncertainty corresponds to 4 degrees of phase at 10 GHz. Such a precision is not achievable with the compact array, as the LO error budget is ~ 10° rms at 10 GHz (1°/GHz).

Long baseline observations will therefore be fundamental in providing registration of HST quality.

Phase Referencing

Making the phase calibration error equal to the LO error appears a reasonable goal in order to reduce the atmosphere/ionosphere uncertainty to an acceptable level. At 10 GHz, 10 degrees of phase corresponds to a positional error of 0''029 on the 6 km baseline. Such a requirement, while still considerably more relaxed than the 0''01 for HST, nonetheless presents a formidable challenge, particularly if it is to be in place before the AT is in operation.

North of declination -25°, the VLA is being used (e.g. Perley 1982) to provide radio positions with errors of 0''05 or less. South of declination -25° the errors in declination increase, becoming ~ 0''15 by declination -40°.

South of declination -25°, it appears then that only long baseline observations will be capable of achieving anything approaching the 0''03 needed for position calibration, even for the compact array.

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It is important to remember that improvements in source positions translate directly into improved baseline vectors and chord lengths on the earth. For geodesy, radio interferometry is unchallenged in determining baselines for distances over ~ 300 km. Below 300 km GPS is ideally suited to surveying, but the precision achievable with GPS decreases significantly over longer baselines (e.g. Stolz et al. 1985).

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D.L. Jauncey

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This requirement carries within it internal conflicts, the degree of conflict depending on the angular resolution. The basic conflict is as follows:

(a) Non variable sources usually have optically thin radio spectra of the form $S \alpha \nu^{-\alpha}$ (where $\alpha \sim 0.7$) and are frequently extended on an arc second scale.

(b) On the other hand the compact sources that are strong at all frequencies ($\alpha \sim 0$) are usually variable, both in intensity and structure (on a milli-arcsecond scale). Moreover, half of these compact flat spectrum sources contain nearby associated diffuse structure which makes them unsuitable for flux density calibrators.

For the compact array there may be a small number of sources that meet the flux density calibration requirements, though it should be stressed that the number is likely to be no more than 2 or 3. For example, in the region $0° > \delta > -45°$, where the strong sources have been surveyed with the VLA at 6 and 20cm wavelengths (Perley 1982), only one source, 0237-233 meets the requirements of being strong (> 3Jy), unresolved, with no detectable nearby structure ($\leqslant$ 0.4% of the core) and that is known to be non variable (Klein and Stelzried 1976).

South of the zenith little information exists on source structure on the angular scale to be sampled by the AT.

It is therefore suggested that a programme be implemented as soon as possible to attempt to determine likely flux density calibrators south of

-45° declination, and to determine their radio structures and monitor their flux densities over a wide range of frequencies, in preparation for the AT.

A possible scenario for the AT would then be to use the small number of prime flux density calibrators to monitor the fluxes of a larger number of unresolved, but probably variable, secondary calibrators.

For the long baseline array, its milliarc-second resolution means that even sources like 0237-233 are unlikely to be LBA flux density calibrators. The SHEVE experiment found, for example, that 0237-233 is a 42 mas double, and therefore unsuitable as an LBA flux density calibrator.

VLBI observations on baselines of length several thousand km show that few, if any sources remain totally unresolved at this resolution. Moreover, any sources that are unresolved on the LBA are even more likely to be flux density variables.

It is unlikely that any sources will be found that meet the primary requirement outlined in the opening paragraph. Consequently a different approach will be needed for the LBA flux density calibration. One such scheme is outlined below.

The first step is to determine the relative antenna gains. For example this can be done provided unresolved components can be found. Suppose that three baselines AB, BC, CA all show visibility curves that are constant, implying a single component unresolved on these three baselines, then

$$\frac{G(A)}{G(B)} = \frac{S(AC)}{S(BC)}$$

where G(A) is the gain of antenna A, and S(AB) is the observed cross correlation on baseline AB.

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Amplitude closure also determines relative gains only, still leaving one antenna to be used as a reference.

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(a) unresolved on the compact array and,
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That source which is least resolved is then that source with the smallest ratio of compact array flux density to correlator output on the shorter LBA baselines. Consensus amongst several sources would then establish some reliability to the final LBA flux density scale.

Such a procedure is not guaranteed of success, since neither those sources with unresolved components nor those that are unresolved on the shorter baselines are yet known. A significant start could, however, be made with the Parkes-Tidbinbilla Interferometer at 2.3 and 8.4 GHz, in determining those sources with low ratios of total flux to correlated flux on this baseline.

Phase Calibration; the Compact Array

The AT requires for phase calibration a relatively dense celestial distribution of unresolved sources, strong at all frequencies and with accurately known and stable positions.

This requirement should be readily met for the compact array from amongst the strong variable sources. As with the flux density calibration, however, the requirements for the LBA are likely to be less easily met as the variable sources often exhibit rapid structural variability, at least at milli-arcsecond scales.

It is important to remember that all of those beautiful "self-cal" procedures that grew out of "phase-closure" (Rogers et al. 1974, Jennison 1958) improve the quality of the map, but provide no information on the position of the map.

Phase calibration has two main astrophysical goals,

(a) to provide map registration so that maps at different frequencies can be reliably overlaid, and
(b) for phase referencing, so that the effects of the atmosphere and ionosphere can be largely removed before making maps.

These are discussed separately below.

Map Registration

Perhaps the most demanding registration requirement will come with the launch of the Hubble Space Telescope, (hopefully) several years before AT completion. HST has a beam width of typically 0.1 arcsecond, pointing capability of 0".007 and an astrometric capability of 0".002. At the very least, one would like to be able to register HST and AT maps to something like one tenth of the HST beamwidth, i.e. ~ 0".01.

For the compact array at 10 GHz, λ/D = 1".0 for the full 6 km baseline, so that a 0".01 positional uncertainty corresponds to 4 degrees of phase at 10 GHz. Such a precision is not achievable with the compact array, as the LO error budget is ~ 10° rms at 10 GHz (1°/GHz).

Long baseline observations will therefore be fundamental in providing registration of HST quality.

Phase Referencing

Making the phase calibration error equal to the LO error appears a reasonable goal in order to reduce the atmosphere/ionosphere uncertainty to an acceptable level. At 10 GHz, 10 degrees of phase corresponds to a positional error of 0".029 on the 6 km baseline. Such a requirement, while still considerably more relaxed than the 0".01 for HST, nonetheless presents a formidable challenge, particularly if it is to be in place before the AT is in operation.

North of declination -25°, the VLA is being used (e.g. Perley 1982) to provide radio positions with errors of 0".05 or less. South of declination -25° the errors in declination increase, becoming ~ 0".15 by declination -40°.

South of declination -25°, it appears then that only long baseline observations will be capable of achieving anything approaching the 0".03 needed for position calibration, even for the compact array.

Optical positions of QSOs have been suggested as one possibility of determining reference positions. A programme is currently underway (White et al. 1985) that aims at ~ 0".05 for sources in the south. The

major obstacle to using such positions is that they are measured with respect to a grid of stars in our galaxy and in no way represent a stable inertial reference frame. The radio reference frame however, can in principle provide an essentially inertial reference frame with respect to an extragalactic grid of distant quasars and galaxies (e.g. Argue et al. 1984).

Establishment of a precision radio reference frame in the south would appear to be highly desirable, preferably on a time scale to precede completion of the AT.

Such a goal is only achievable with a programme of long baseline observations starting immediately. With an ultimate precision of 0".01 or better this programme may meet the HST registration requirements, as well as providing a major part of the LBA phase calibration requirements.

Geodesy

It is important to remember that improvements in source positions translate directly into improved baseline vectors and chord lengths on the earth. For geodesy, radio interferometry is unchallenged in determining baselines for distances over ~ 300 km. Below 300 km GPS is ideally suited to surveying, but the precision achievable with GPS decreases significantly over longer baselines (e.g. Stolz et al. 1985).

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Draft AT Doc. No. AT/20.1.1/017

A Brief Look at AT Calibration

D.L. Jauncey

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